Studies of Ionospheric Plasma Structuring at Low Latitudes from Space and Ground, their Modeling and Relationship to Scintillations

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LONG-TERM GOALS

This program combines observations and modeling of the nighttime ionosphere to come to a better physical understanding of the factors that contribute to the day-to-day variability of the development of ionospheric irregularities. The scope encompasses irregularities developing at equatorial and mid-latitudes on Earth. There is a critical need to be able to forecast these irregularities, as they can have severe effects on transionospheric radio wave propagation, and can thus degrade the utility of satellite navigation and communication systems. The long-term goal of this program is to increase our understanding of the physical parameters that control when and where irregularities develop in addition to being able to specify regions of the ionosphere that will have an adverse effect on radio wave propagation.

OBJECTIVES

The objective of this program is to come to a better understanding of the fundamental drivers behind the development of ionospheric irregularities and their effects on radio wave propagation.

APPROACH

This program combines optical observations obtained from space- and ground-based optical platforms with a physics-based model. The observations come from a variety of sources. Data from satellites, including the Global Ultraviolet Imager (GUVI) on NASA”s Thermosphere, Ionosphere, Mesosphere, Electrodynamics (TIMED) satellite, which provides global images of the Earth”s ionosphere, and the Air Force Communications/Navigation Outage Forecasting System (C/NOFS) satellite, which provides in-situ measurements of parameters such as electron density and electric fields. Ground-based data come from several optical imaging systems and GPS scintillation monitors operated by the Remote Sensing and Space Science group at the University of Illinois at Urbana-Champaign. The data collected by GUVI have been compared to the output from the NRL SAMI3 model developed at the Naval Research Laboratory. The input parameters (electric fields and neutral winds) of the SAMI3 model can be varied to match the output of the model to the GUVI observations. In addition, data from the ground-based imaging systems, based upon the NRL Portable Ionospheric Camera and Small-Scale Observatory (PICASSO), have been deployed in South America to collect additional ground-based data to compare to the modeling results. These data are also being analyzed separately and in conjunction with other available datasets to understand the driving factors affecting the irregularity

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14. ABSTRACT
This program combines observations and modeling of the nighttime ionosphere to come to a better physical understanding of the factors that contribute to the day-to-day variability of the development of ionospheric irregularities. The scope encompasses irregularities developing at equatorial and mid-latitudes on Earth. There is a critical need to be able to forecast these irregularities, as they can have severe effects on transionospheric radio wave propagation, and can thus degrade the utility of satellite navigation and communication systems. The long-term goal of this program is to increase our understanding of the physical parameters that control when and where irregularities develop in addition to being able to specify regions of the ionosphere that will have an adverse effect on radio wave propagation

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growth and their effects of radio wave propagation. Novel techniques are needed to jointly combine the data collected by various modalities of instrumentation.

At the University of Illinois at Urbana-Champaign, the work has primarily been carried out by the PI, Prof. Jonathan Makela, and a Ph.D. student, Mr. Ethan Miller, who completed his degree in the summer of 2009. In addition, the PI has interacted on this program with Prof. Sunanda Basu, Dr. Sarah MacDonald, and Dr. Joseph Huba at the Naval Research Laboratory.

WORK COMPLETED

The following tasks have been completed:

(1) GUVI data over a 16-month period have been obtained and analyzed to search for indications of day-to-day variability in the global-scale ionosphere that could be related to irregularity generation/suppression.

(2) The SAMI3 model has been exercised at NRL to recreate the morphology seen in the GUVI data in order to understand the possible physical driving mechanisms behind the variability seen in the GUVI data.

(3) A multi-instrument study was performed to understand the effects ionospheric irregularities have on GPS-based navigation systems at mid-latitudes.

(4) A ground-based imaging system and GPS scintillation have been deployed to the Cerro Tololo InterAmerican Observatory near La Sarena, Chile, to collect data used in this study. Unfortunately, due to continued logistical issues in importing a second imager into Colombia, the conjugate observations planned for this work were not obtained, despite the best efforts of the PI.

(5) The data from the Chile imager have been analyzed in conjunction with occultation data from the COSMIC/FORMOSAT satellite constellation to understand the electrodynamical coupling along magnetic field lines during periods of equatorial irregularities.

(6) Data from the Chile imager and an imager on the Haleakala Volcano, Maui, HI have been compared to in-situ data collected by the C/NOFS satellite to study conditions on days when irregularities developed versus those on which no irregularities were observed.

(7) Several new analysis techniques have been developed to jointly analyze data collected from the different modalities of instrumentation (e.g., airglow, GPS occultation, coherent scatter radar).

(8) A ray-tracing technique was developed to simulate the optical emissions obtained from the 3D NRL Bubble model of Dr. Joseph Huba.

RESULTS

In the duration of this study, we have learned that irregularities at mid-latitudes can be generated by intense ionospheric flow, even in the absence of gradients in electron density. This aspect of irregularity generation had not been appreciated in the past, and represents a new step in our understanding of irregularity generation mechanisms.

At lower latitudes, we have learned that the decrease in separation of the equatorial ionization arcs, which we had previously associated with decreased scintillation activity, can be simulated in the SAMI3 model by reversing the upward vertical drift in the mid-afternoon time sector at the magnetic equator. The reversal appears to be related to the appearance of a counter-electrojet feature, which is a longitudinally confined feature. Thus, we have shown that the day-to-day variability in the occurrence of equatorial scintillations can be controlled by the occurrence of the counter-electrojet.

From our work combining different modalities of observations, we have demonstrated a new method from which the altitude of scintillation-causing irregularities can be estimated. From a short-term study (one month), we demonstrated that our method results in estimates of scattering heights between approximately 200-350 km. This knowledge can be used to better constrain phase-screen models used to predict the effects of the scintillation-causing irregularities for ground-based receivers.

By tracing through the 3D NRL Bubble model provided by Dr. Joseph Huba we have investigated the relationship between simulated images of optical emissions and the data collected by our group"s imaging systems around the globe. The two compare favorably, to the limit of the resolution of the provided model output. As the 3D NRL Bubble model continues to evolve and consider additional parameters, we now have the mathematical framework and code in place to rapidly simulate the optical emissions for comparison to actual data.

IMPACT/APPLICATIONS

As described above, our results shed new light on our understanding of irregularity processes that can have severe effects on transionospheric radio wave propagation. As we continue to refine our understanding of these processes and controlling factors, we can better specify the ionospheric state, leading to improved specification models and forecasts. The data collected under this award from Chile, which is planned to be continued, is providing understanding of the differences in the occurrence of these irregularity structures during the transition into solar minimum conditions. Our work at low latitudes, especially, demonstrates the value of new measurements and combining these with existing infrastructure for obtaining crucial information on the ionospheric state not previously available.

RELATED PROJECTS

A related project is funded by the National Science Foundation, entitled "Collaborative Research: Coordinated Imaging and Scintillation Study of the Conjugate Nature of Equatorial Plasma Irregularities." This is a collaborative project with colleagues at Cornell University and Virginia Polytechnic Institute and State University. Through this project, we were able to leverage instrumentation and expertise for measuring the ground-based scintillation effects on the Global Positioning System signal caused by ionospheric irregularities. This instrumentation is collocated with the imaging system installed at the Cerro-Tololo InterAmerican Observatory in Chile.

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HONORS/AWARDS/PRIZES

Ronald W. Pratt Faculty Outstanding Teaching Award, Department of Electrical and Computer Engineering, University of Illinois at Urbana-Champaign, 2009.